# MATHUSLA status update

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on behalf of the MATHUSLA Collaboration

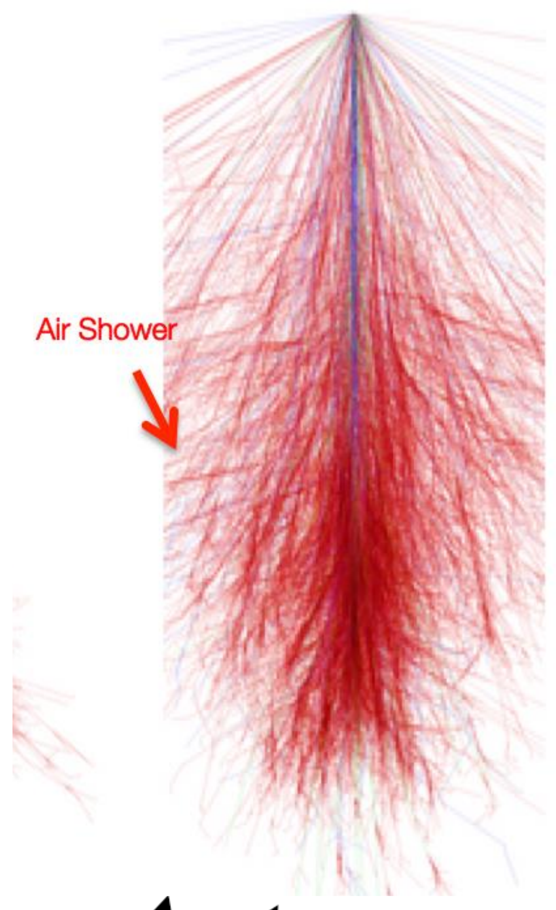
**LLPX workshop**
9 Nov 2021

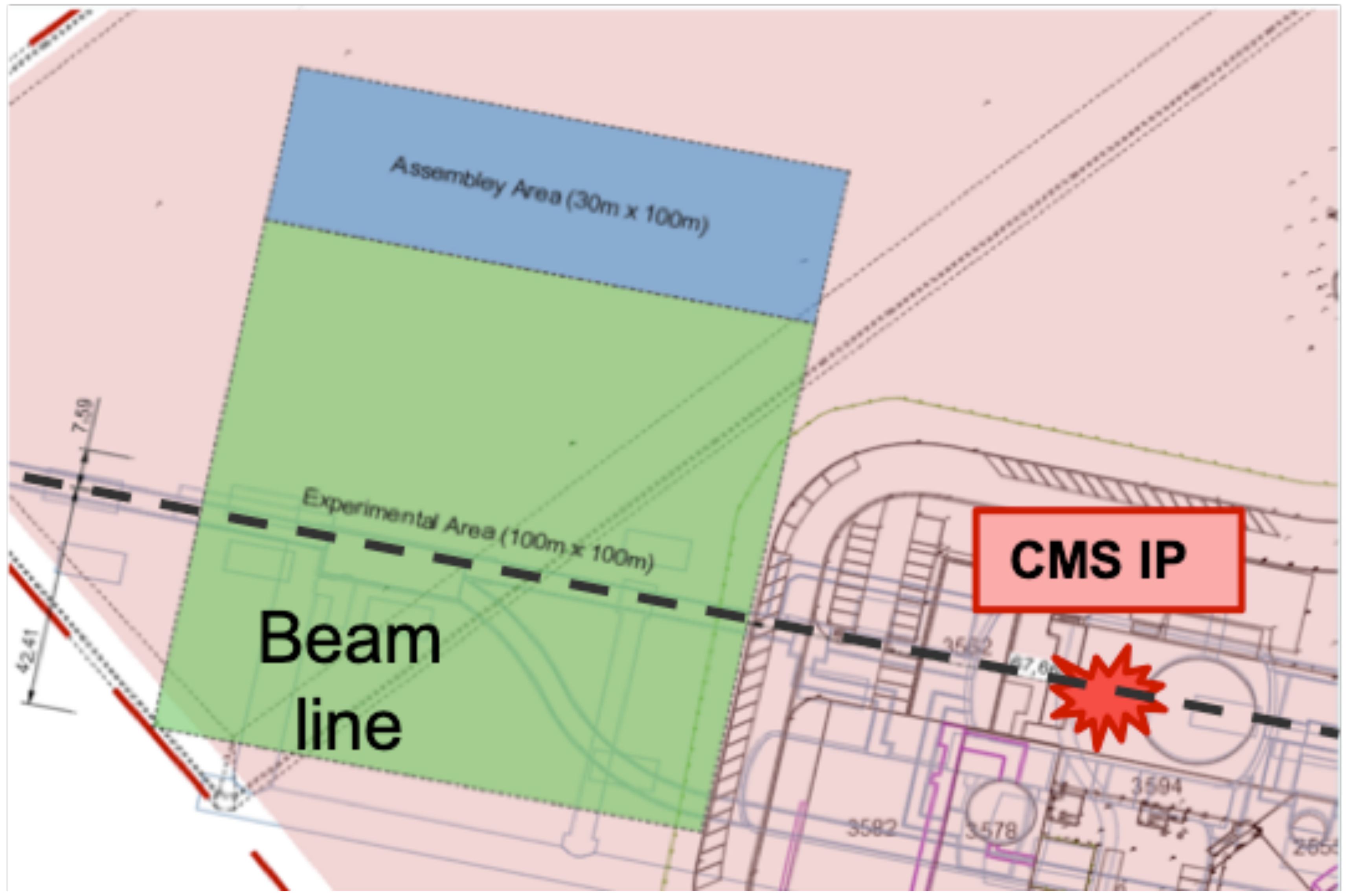
# MATHUSLA concept

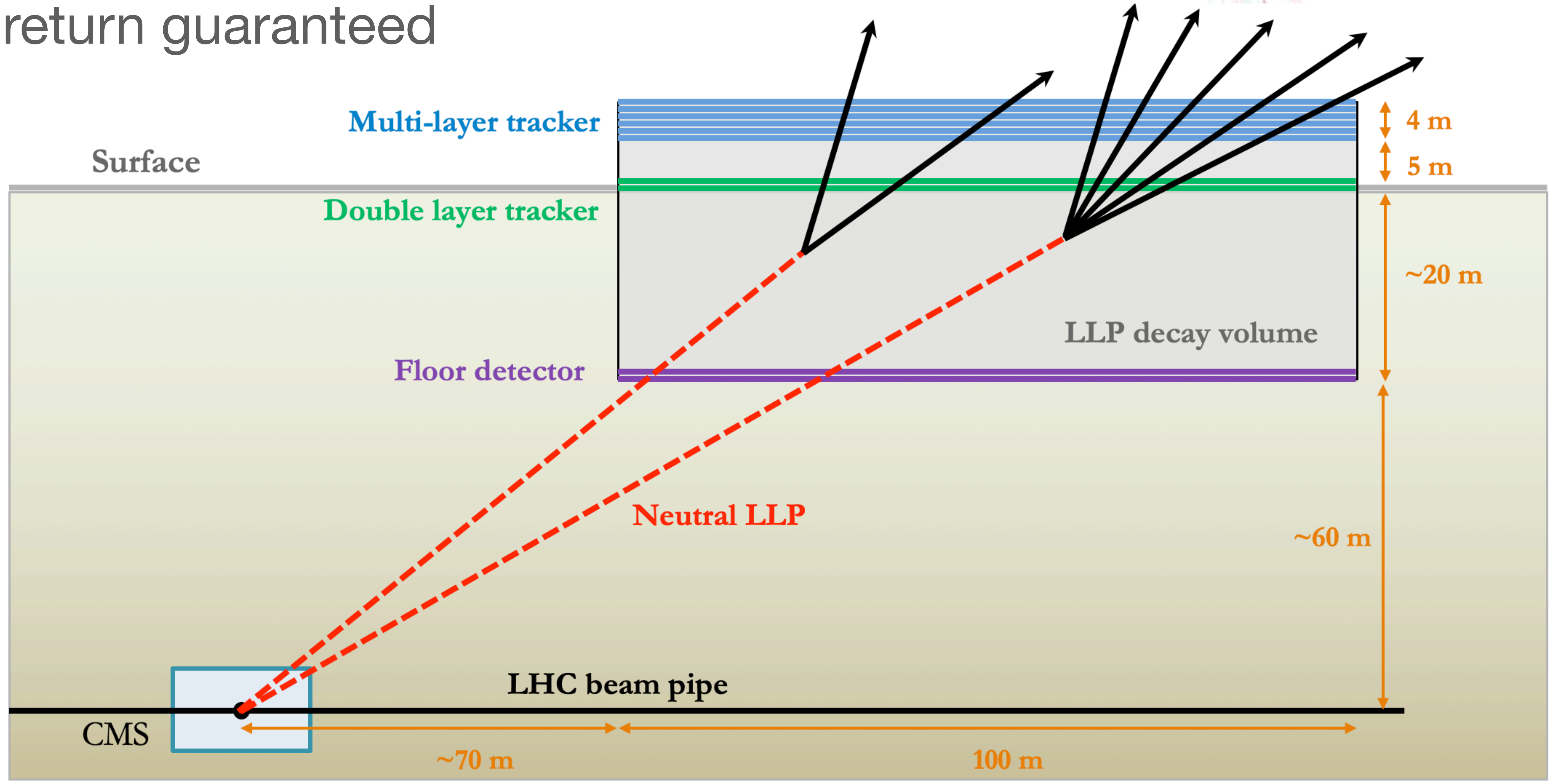
MATHUSLA: MAsive Timing Hodoscope for Ultra Stable neutraL pArticles

Web: https://mathusla-experiment.web.cern.ch

- Target: **ultra long-live particles** (up to Big Bang Nucleosynthesis limit ($10^7$ - $10^8$ m) lifetime)
- To be placed on the surface **above CMS during HL-LHC**
- Large volume filled with air as decay volume with several scintillator layers for tracking
  - LLPs decaying inside MATHUSLA are reconstructed as **displaced vertices**
  - Aiming for ~**zero background** analysis (~100m rock shielding)
  - Measurements of cosmic rays showers! Physics return guaranteed



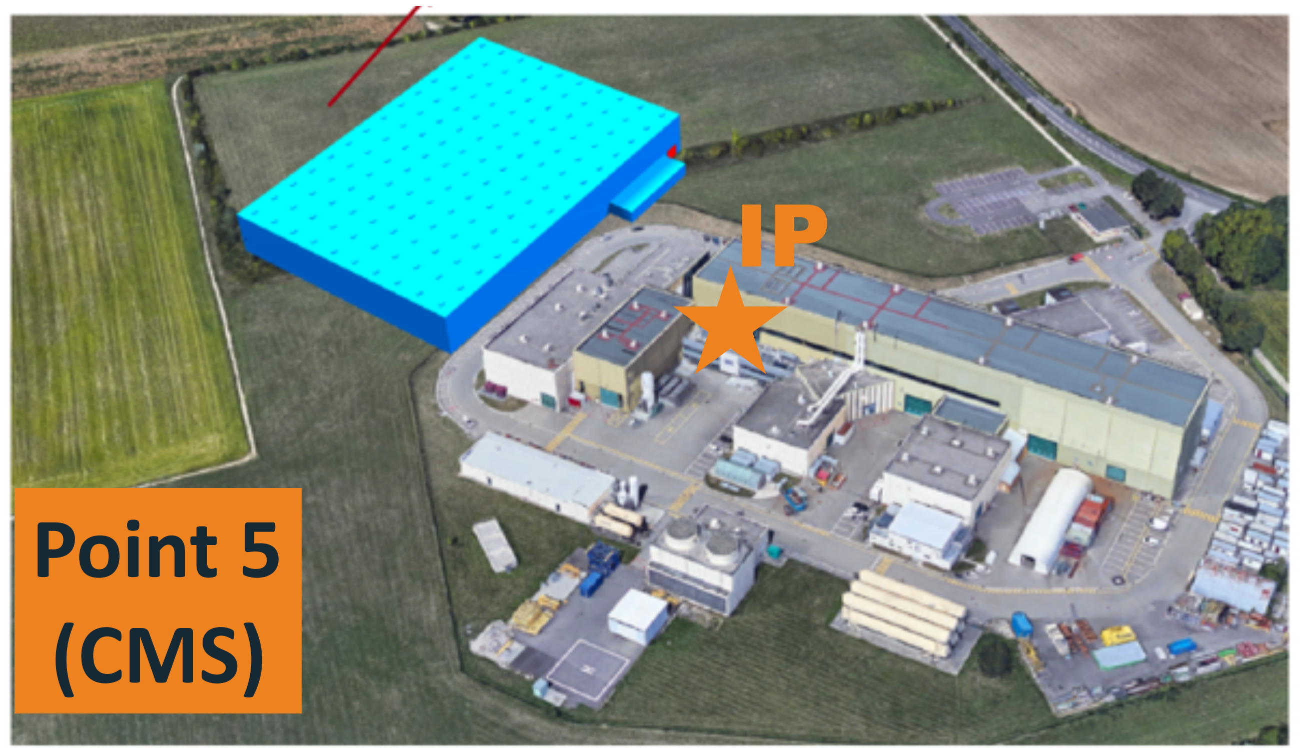



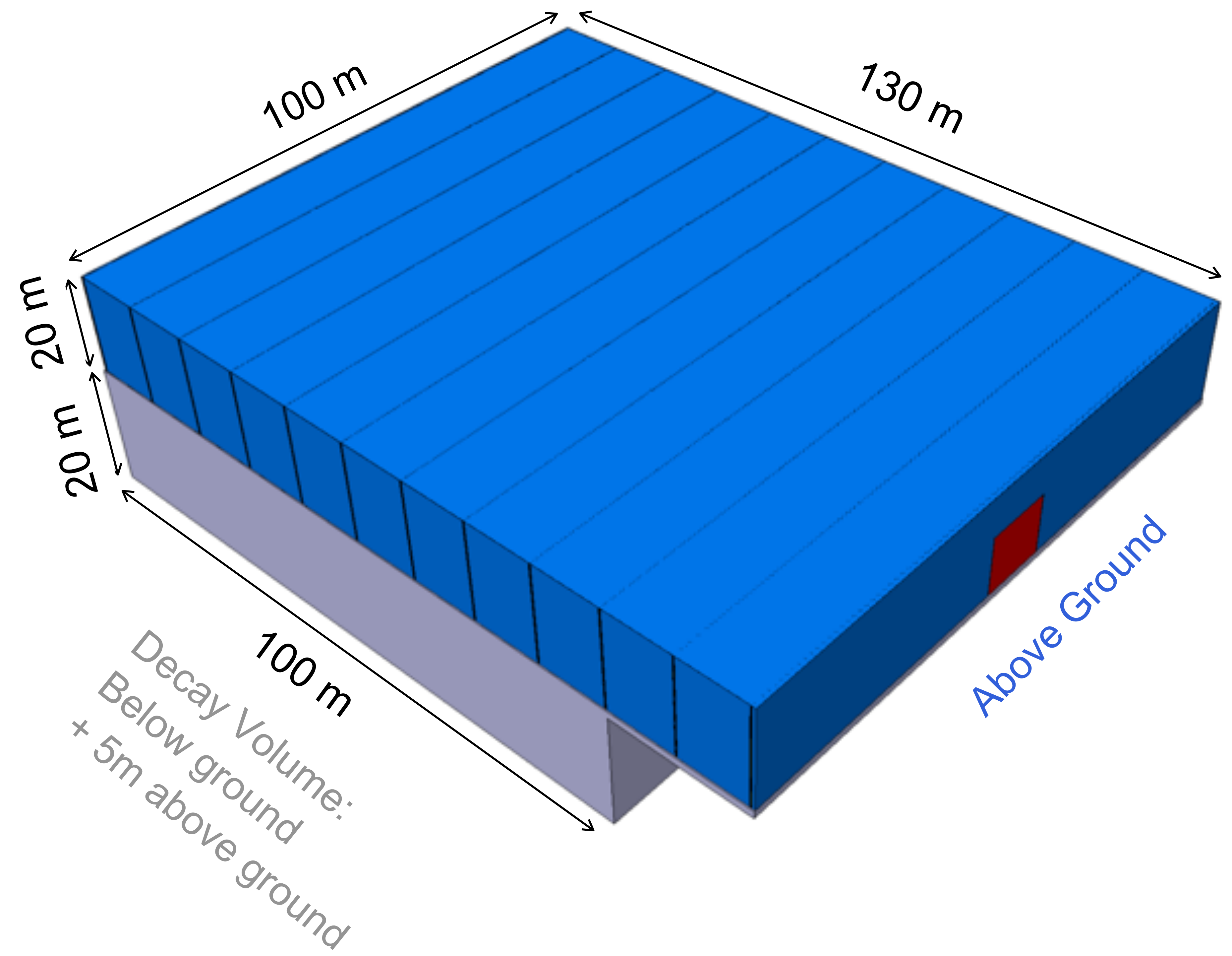



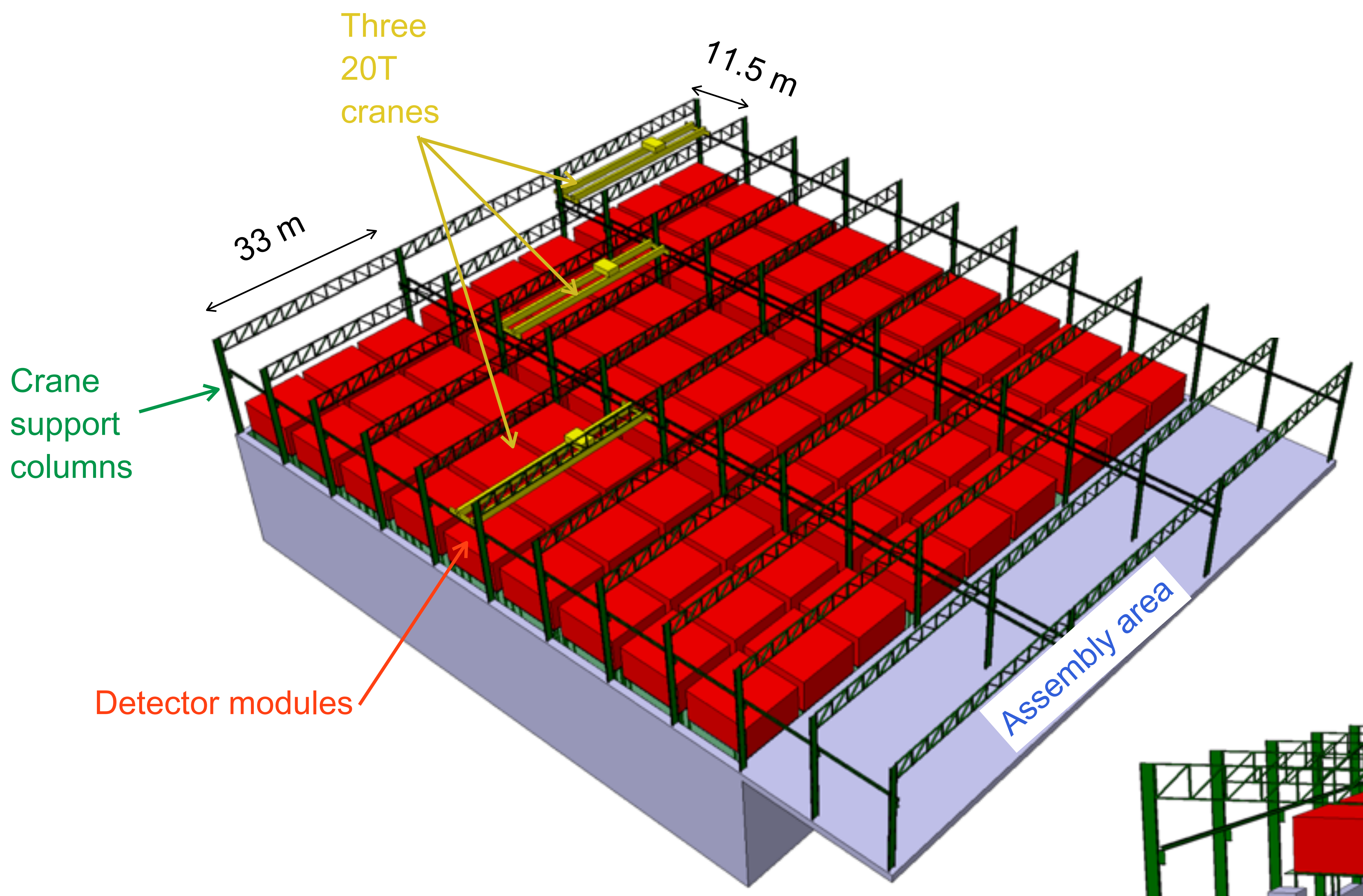
# MATHUSLA layout

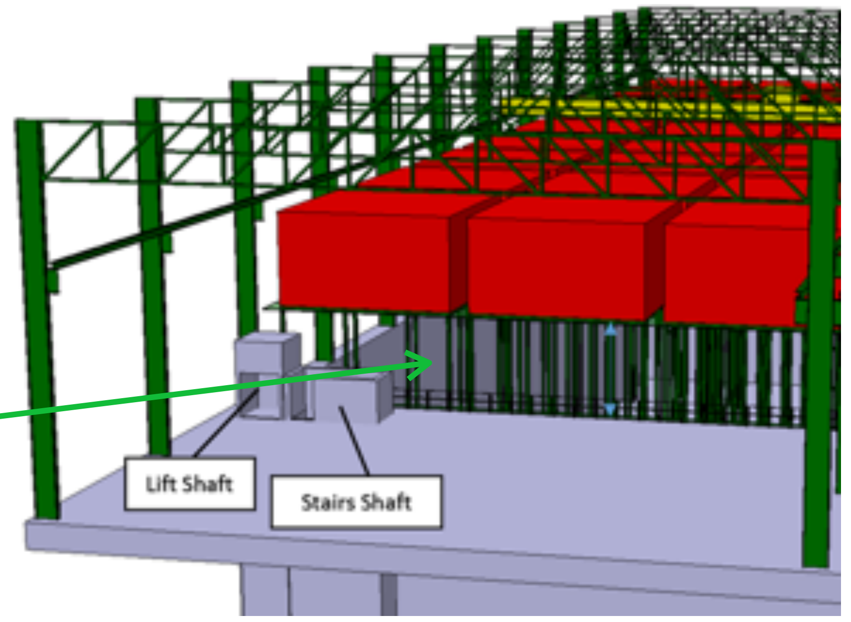
- Worked with civil Engineers to define the building and the layout of MATHUSLA at P5
- Layout restricted by existing structures based on current concept and engineering requirements

- Decay volume ~100 x 100 x 25 m$^3$
- Modular design (9 x 9 x 25 m$^3$)



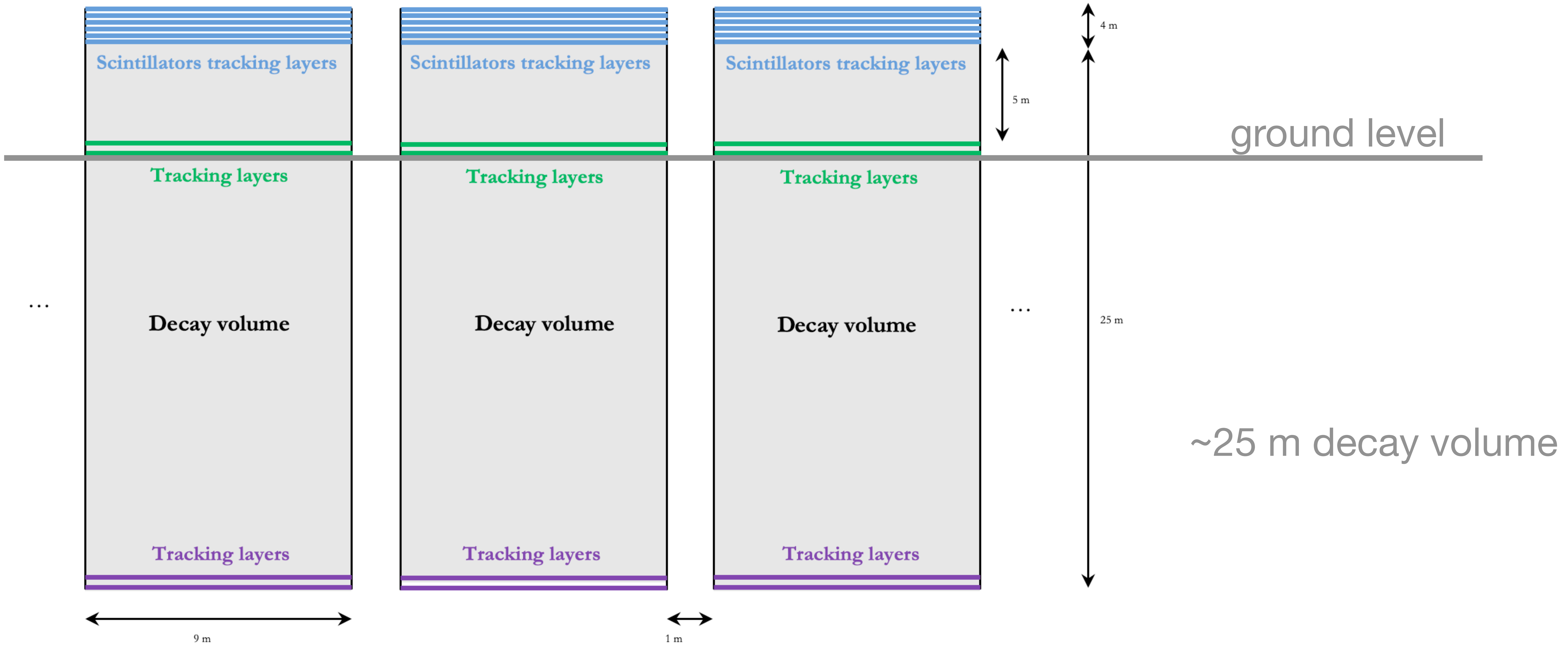



# New additional tracking layer

- Individual detector units: 9 x 9 x 30 m$^3$

6 layers of tracking/timing detectors separated by 80 cm

Current model includes 2 additional tracking layers on the top part of the decay volume (ground level)




Double layer floor detector (tracking/timing)

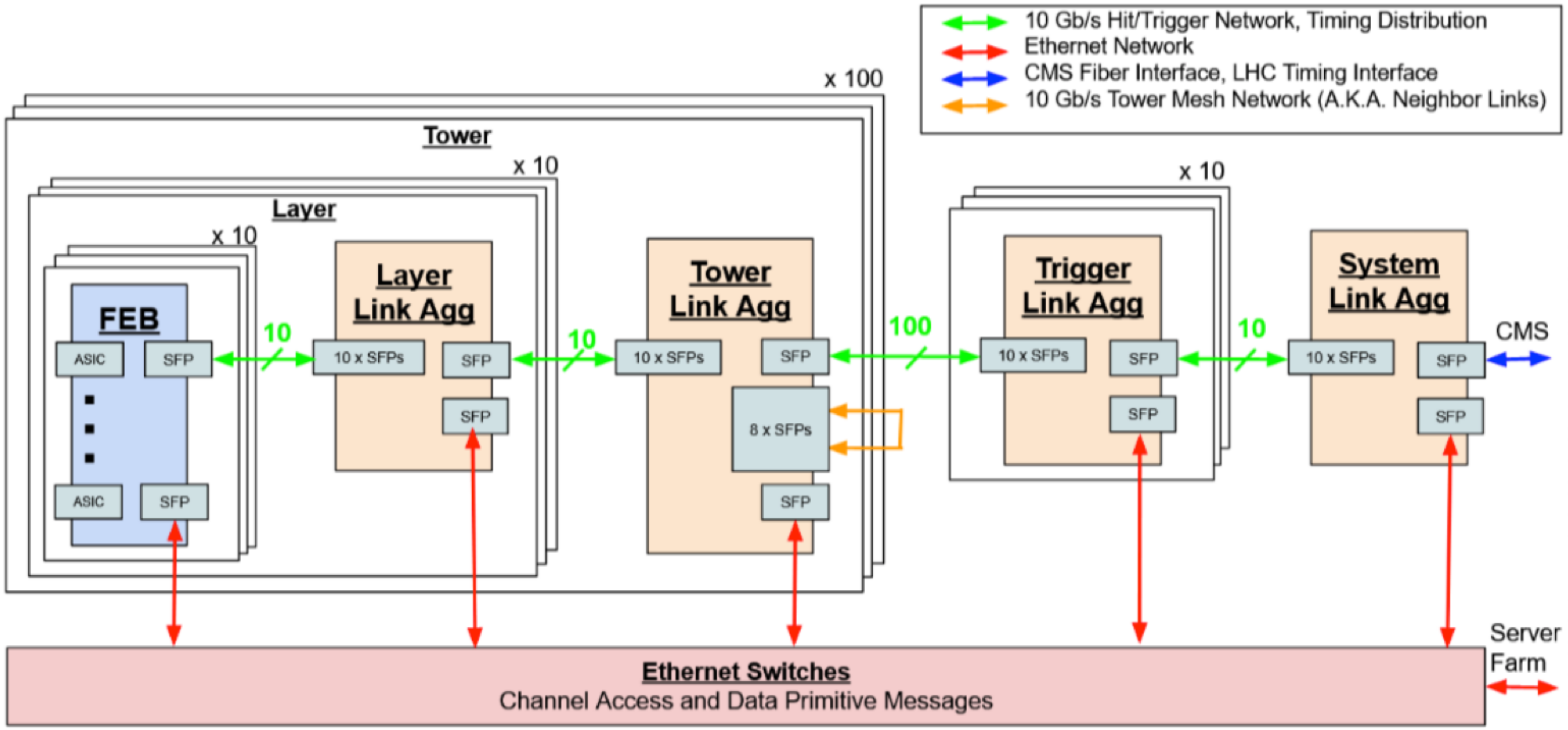
# Ongoing developments

*Latest status reports
- LHC LLP Nov 2020
- LHC LLP May 2021
- PBC March 2021

- Detector R&D:
  - Trigger & DAQ design
  - Extruded scintillators, fibers, SiPMs
  - Simulation studies (LLP and background)

- Cosmic rays studies
  - CR physics case white paper coming out this year 2021
  - Contains the physics case for adding a layer of RPC detector

# DAQ design



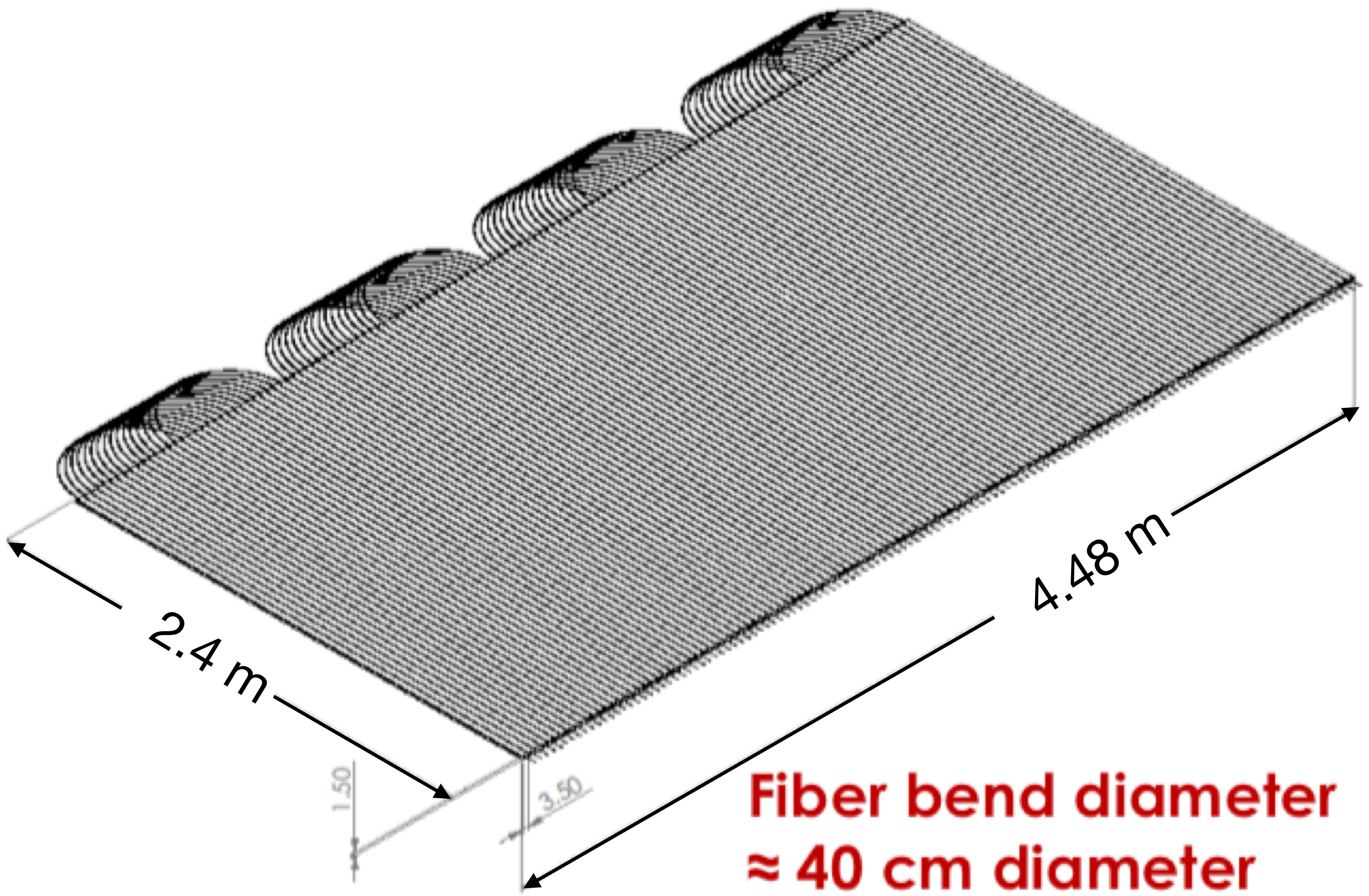

- DAQ
  - Modular design of the Front End Boards (FEB) and link aggregation boards
  - All hits stored in buffer storage
  - Data rate and volume is well within COTS servers

- Trigger
  - Tower aggregation module triggers on upward going **tracks** within 3 x 3 tower volumes
  - Select data from buffer for permanent storage

- Trigger to CMS
  - Upward-going **vertex** forms trigger to CMS
  - MATHUSLA trigger latency estimates appear compatible with CMS L1 latency budget

# Detector Plane layout studies

- Extruded scintillator bars with wavelength shifting fibers (WLSF) connected to SiPMs
  - Chosen over RPCs thanks to low operating voltage (~30 V), no gas involved (global warming potential), less sensitive to temperature and pressure variations
- Considering some possible layouts for scintillating detector planes
  - Layout option where all SiPM connections are on one side of layer with 2.4 m extruded bars
  - Looking at options that have number of bars that are multiples of 16 (may be convenient for DAQ)
- 128 bars of dimensions result in 2.4 x 4.48 $m^2$ units (8 units to cover ~ 9 x 9 $m^2$ with overlaps)

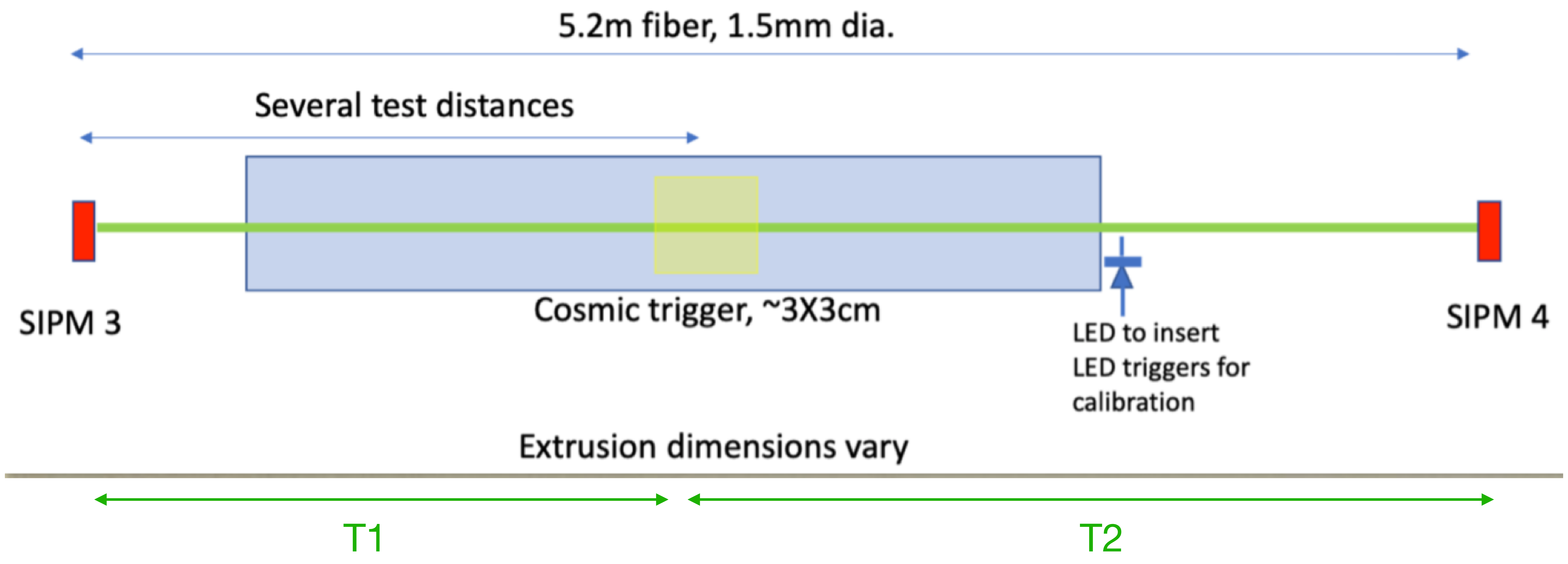



- Main advantages
  - SiPMs on same side simplifies DAQ read out
  - Cooling, insulation all in one unit in one side

- Complications
  - Assembly of WLS fibre and higher probability of damaging fibre during installation
  - Requires protective cover on WLS fibres

# Scintillator timing and testing

- Use difference in arrival time between separate measurements at two ends of extruded scintillator

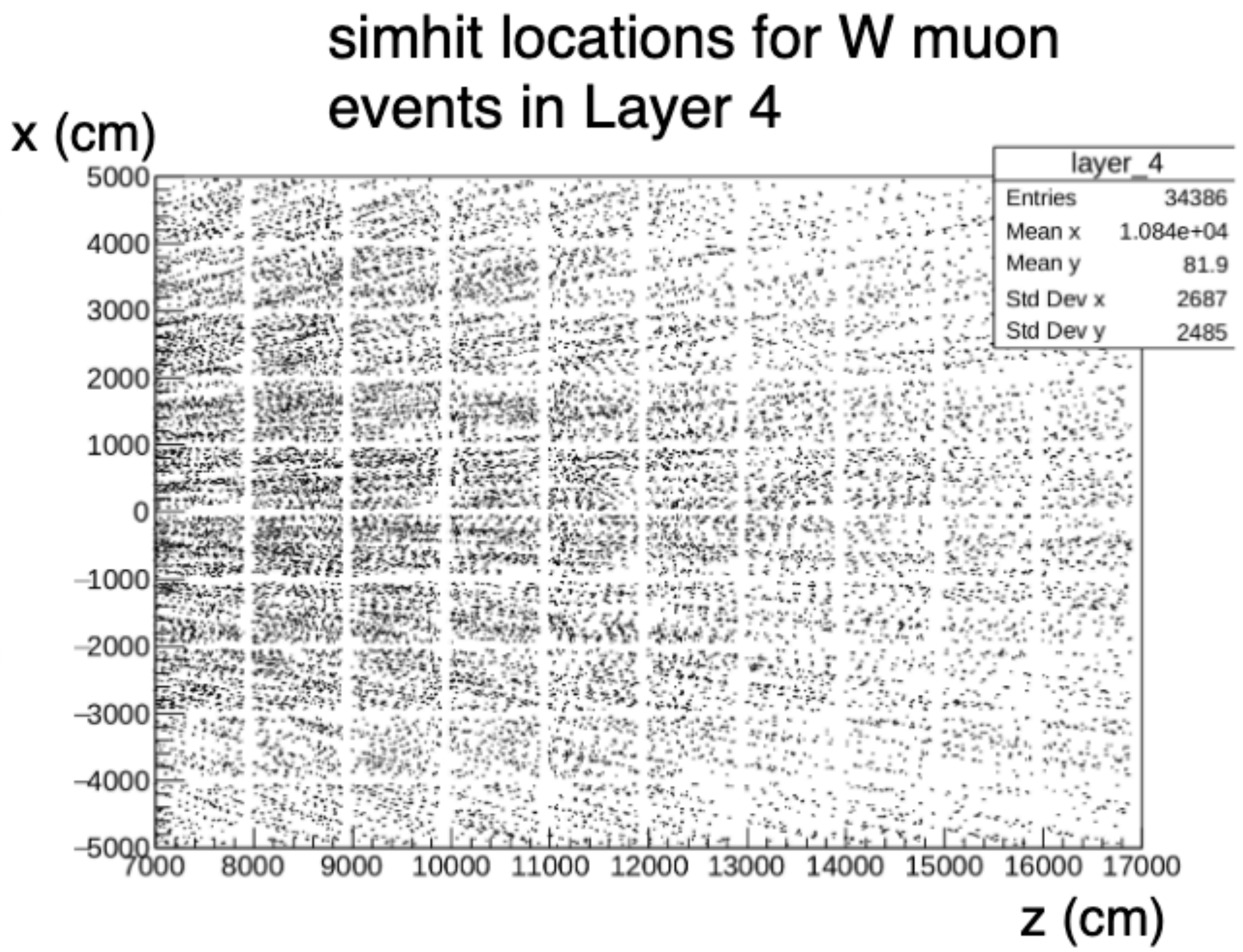



- Critical features for detector design
  - Separate downward from upward going tracks
  - Reject low beta particles from neutrinos
  - 4D tracking and vertexing to reduce fakes/combinatorics
    - Target timing resolution is ~1ns along the bar

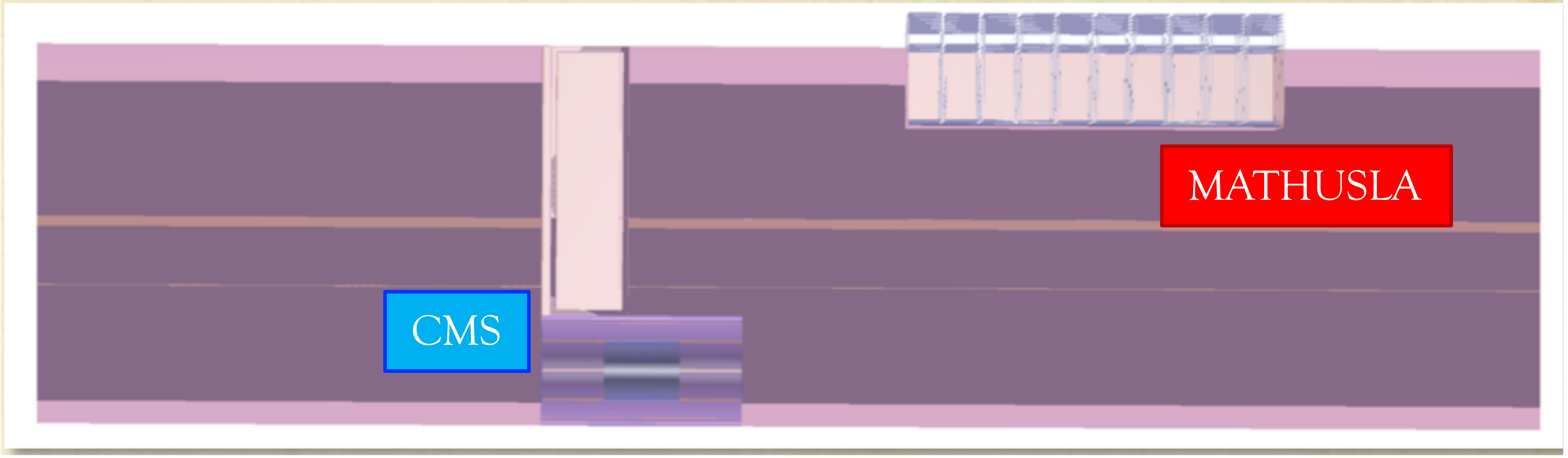
- Ongoing studies on:
  - SiPM/WLSF/scintillator characterisation for different vendors/types
  - Dark current and SiPM cooling
  - Optimisation of the geometry (thickness of the scintillator bars, number/thickness of fibers...)
  - Optimisation of physics requirements vs cost

# Simulation of backgrounds and signal

- Use Geant to model particle interaction with matter
- Cavern, access shaft, CMS, rock, and detector are all modelled
- Rock is from a geological survey (same as used in the test stand)
- Analysis software uses Kalman Filtering to reconstruct tracks and form 4D vertices




- Backgrounds creating upward-going tracks under study:
  - Upward-going muons from collisions (Pythia8)
  - Backscatter (to upward-going) from downward going cosmic (Parma)
  - Neutrino interactions (Genie3)
    ~30 interactions/year, reduced to <1 event/year after track selection requirements



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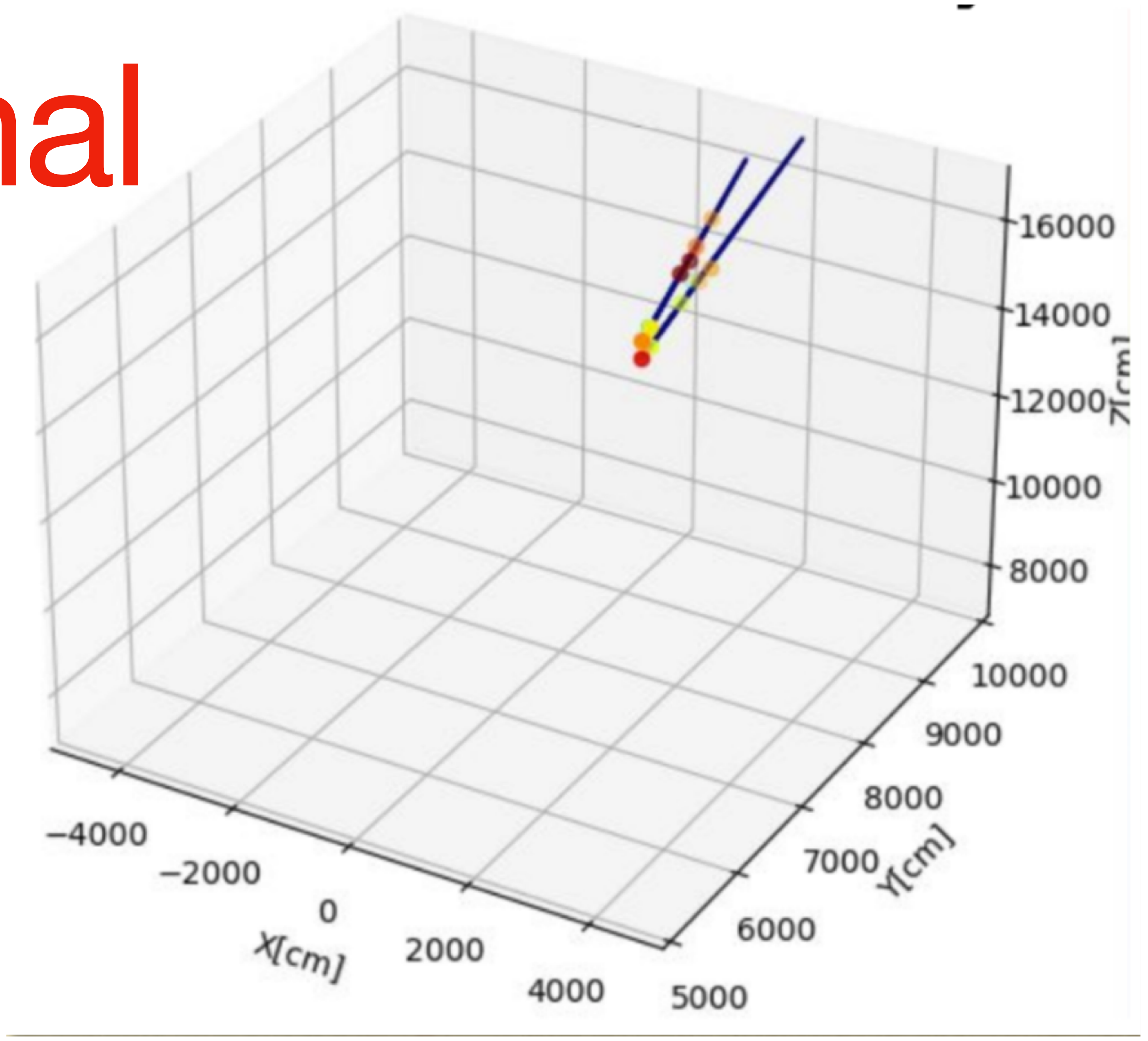


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- Cavern, access shaft, CMS, rock, and detector are all modelled
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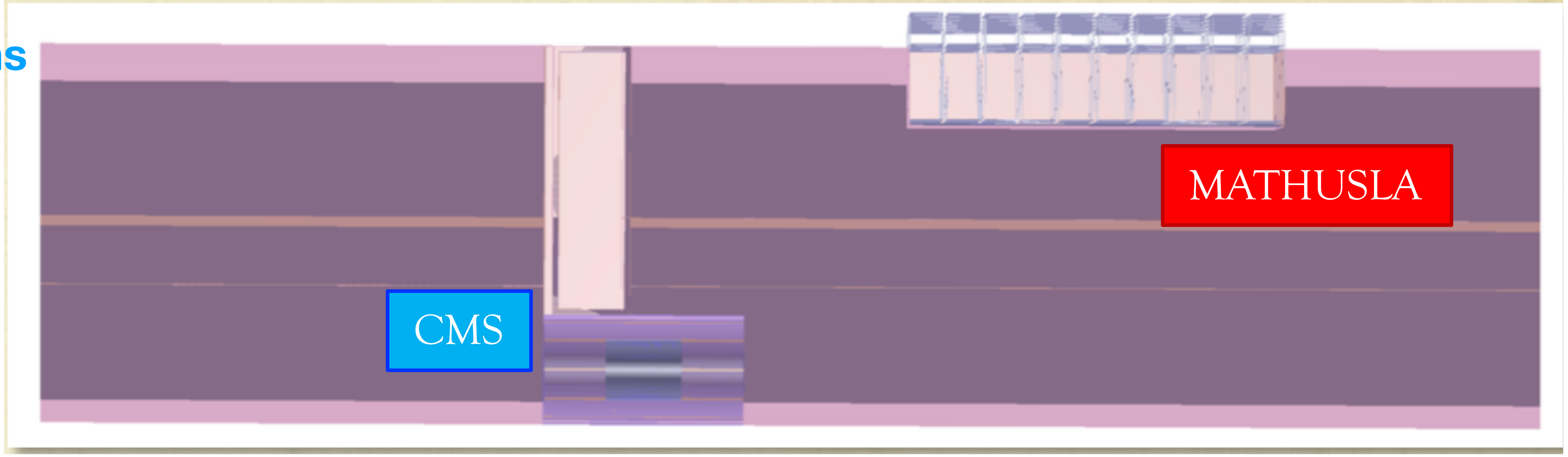
- muon passes through a gap in the floor and knocks off an electron

- Backgrounds creating upward-going tracks under study:
  - **Upward-going muons from collisions (Pythia8)**
  - Expect ~10 muon events over lifetime of HL-LHC



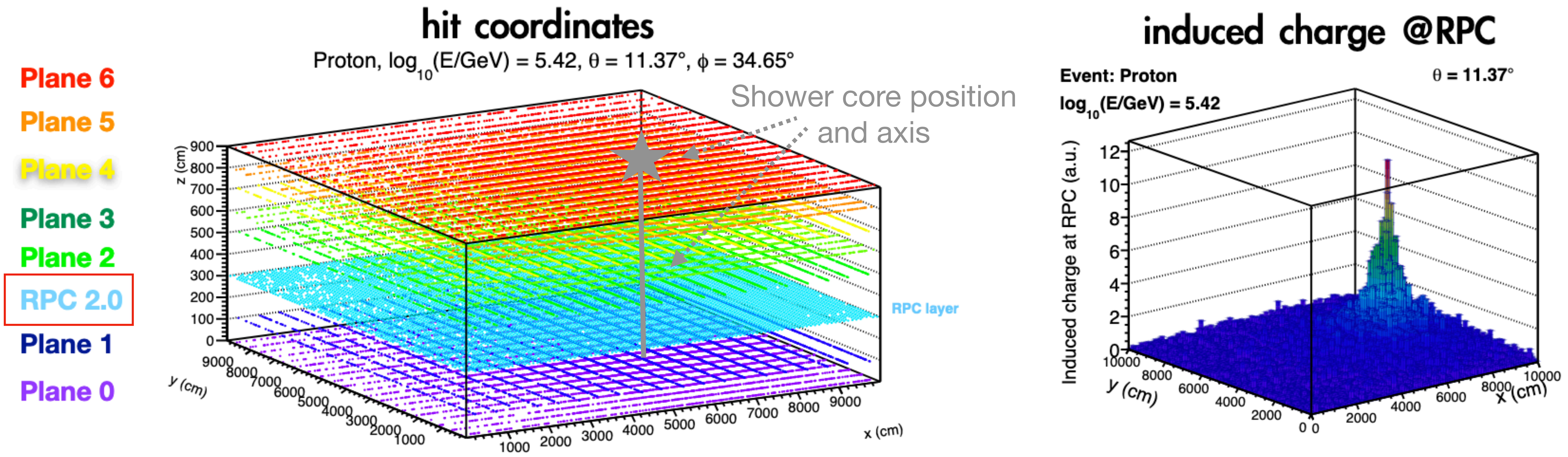

- Background rejected with a high-coverage veto + topological constraints on the vertices

# EAS studies with scintillators and RPC

- MATHUSLA has good performance for inclined (>60º) air showers induced by Fe/H nuclei
- Scintillator bars saturate very quickly: no measurements of charged particles density possible!
- Evaluating the addition of an RPC layer to enhance Mathusla performance for vertical Extensive Air Showers (EAS )
  - Simulation studies of vertical and inclined EAS well advanced

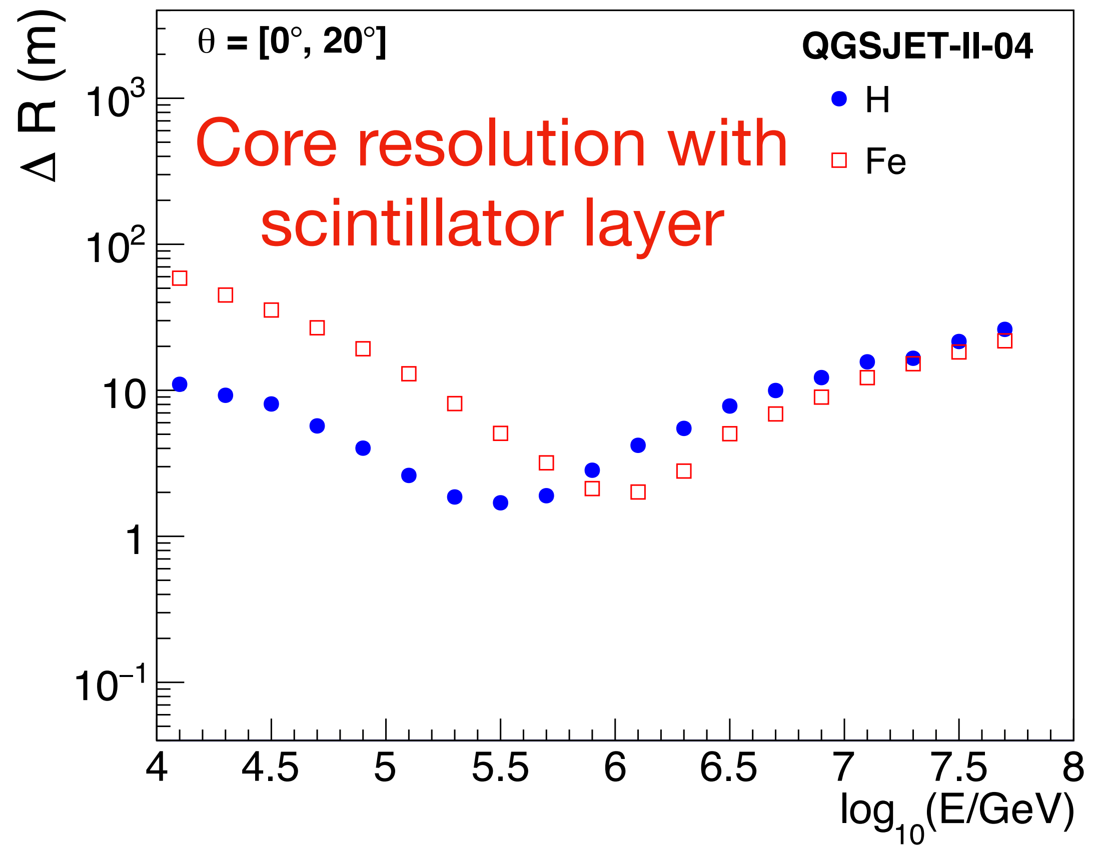
Vertical event

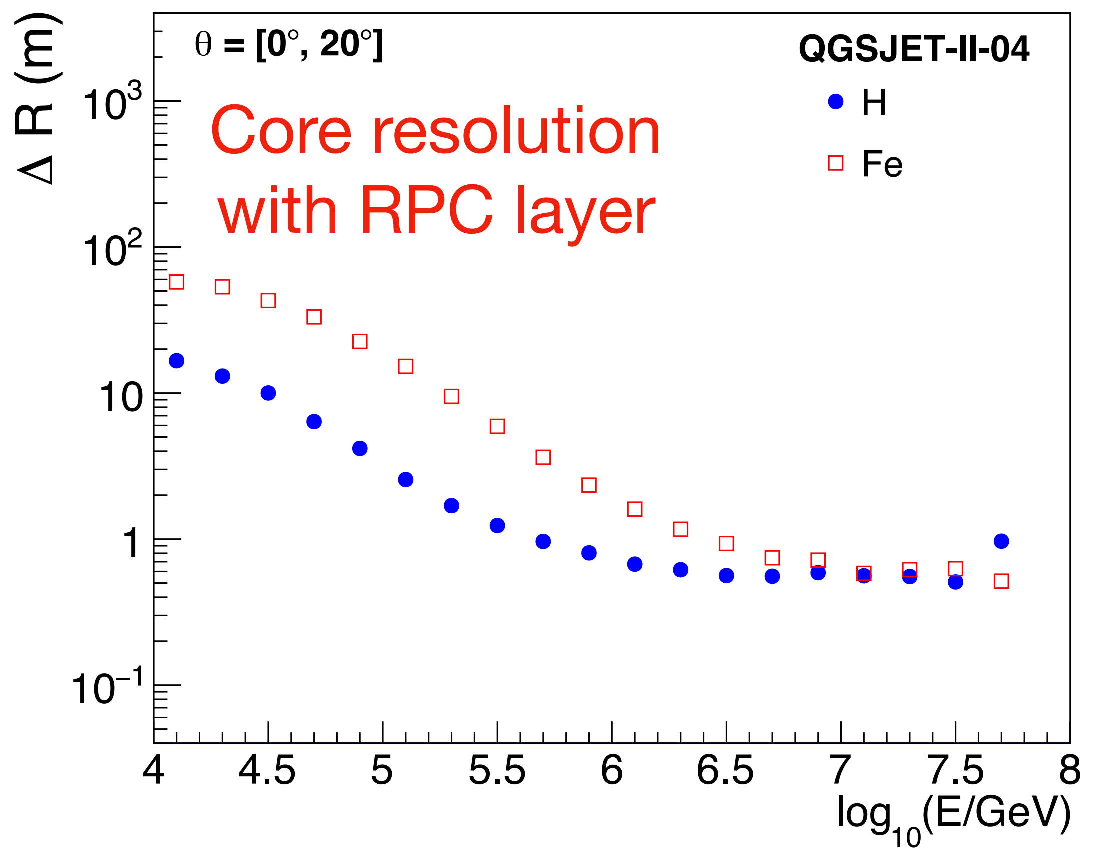
- For these tests, considered 4cm x 5m scintillator bars.
- Coordinate of the hit = center of the bar



# CR studies with RPC-physics

- A layer of RPC with digital and analog readout (like ARGO-YBJ) would greatly improve the performance of MATHUSLA
- CR physics
  - Reconstruction of the all-particle energy spectrum from vertical and inclined events at PeV energies
    - Sensitive to primary cosmic ray (CR) energy around the knee of the CR energy spectrum
  - Study the composition of CR
    - can measure the core position, charge density profiles, arrival times/direction of the shower front..
      - use to estimate the primary particle energy and mass
      - estimate the CR composition using the total number of charged particles and the steepness of the lateral distributions of charged particles
  - Obtain large scale anisotropy maps in arrival directions of CR
    - Possible to obtain maps with very good angular resolution using the capabilities of the RPC layer
    - Measure small scale anisotropies in arrival directions and search for point sources



# Conclusion and plans

- MATHUSLA has extensive reach and versatility to probe the LLP landscape

- Significant progress is being achieved on multiple fronts:
  - simulation of rare backgrounds
  - DAQ design
  - scintillator/ fiber/SiPM properties
  - cosmic ray physics case for an additional layer of RPC
    - Guaranteed physics return
    - Cosmic ray studies with MATHUSLA will be published soon!

- Hope to finish TDR by early 2022, followed by prototype module and full detector for HL-LHC

- New member contributions always welcome!

# MATHUSLA Documentation

- Original idea: J.P. Chou, D. Curtin, H. Lubatti arXiv 1606.06298
- Mathusla physics case - theory white paper arXiv 1806.07396
- Letter of Intent arXiv 1811.00927
- Input to European Strategy for Particle Physics arrive arXiv 1901.04040
- Updated Letter of Intent: arXiv 2009.01693
- MATHUSLA Test Stand: NIMA 985 (2021) 164661

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